

Plasticity at High Pressures and Strain Rates Using Oblique-Impact Isentropic-Compression Experiments



Jeffrey N. Florando
(925) 422-0698
florando1@llnl.gov

Various aspects of the Laboratory's national security mission depend on accurate computer code simulations of high-strain-rate plastic flow (*i.e.*, nonreversible deformation) under conditions of high hydrostatic pressures. While progress has been made in recent years, especially at the extreme cases of pressure and strain rate, there is still an uncertainty in understanding the strength of materials under conditions of combined high strain rate (10^4 to 10^6 s⁻¹) and high pressure (1 to 100 GPa).

Current strength models used in simulations include some physically based models such as the Mechanical Threshold Stress formulation, which has over 20 parameters. The uncertainty in the values for these parameters as well as values for the parameters in other physically based models is under question due to the inherent difficulties in conducting and extracting high-quality experimental data in the high-pressure and high-strain-rate regimes. The experimental studies of material strength at these pressure and strain rate regimes will further the understanding of the underlying physical strength mechanisms needed for accurate material strength models.

Project Goals

The goals of this project are to develop an oblique-impact isentropic-compression experiment (Fig. 1) to measure the strength of materials under a condition of combined high strain rate (10^4 to 10^6 s⁻¹) and high pressure (1 to 100 GPa). The isentropic compression allows for high pressures to be achieved over relatively long time frames (micro-seconds), and the oblique impact allows for a measurement of the strength properties under pressure. The strength data will then be used to refine and enhance the current strength models. When completed, this work will increase the Laboratory's ability to develop predictive strength models for use in computer code simulations.

Relevance to LLNL Mission

Understanding and simulating the strength of materials under dynamic loading conditions is a major component of the Laboratory's Stockpile Stewardship Program and is applicable to future National Ignition Facility (NIF) experiments. These computer code simulations, however, require additional experimental data in order to develop new models and validate the existing codes.

FY2007 Accomplishments and Results

The oblique-impact isentropic-compression experiment requires a keyed barrel. The experiments are developed at LLNL and tests are performed at Brown University. A formal collaboration has been established with a three-year contract that is now in place. The first year

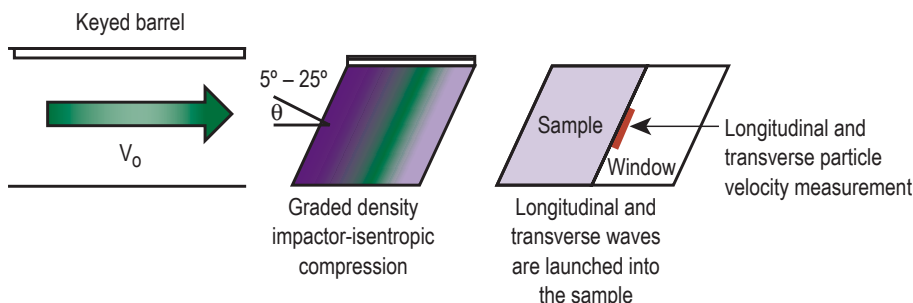


Figure 1. Oblique-impact isentropic-compression experiment.

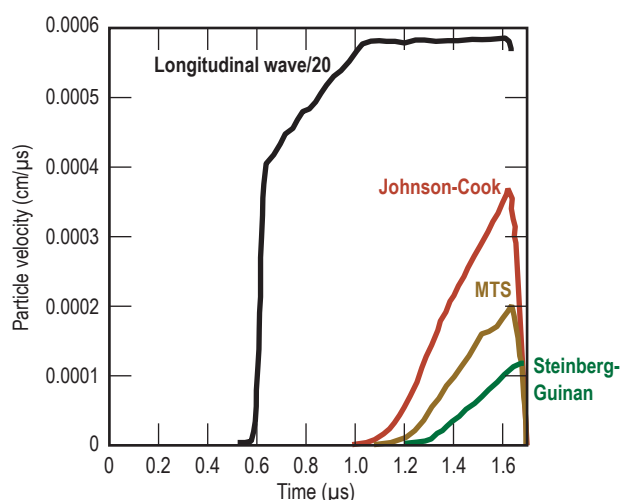


Figure 2. 3-D hydrodynamics simulation showing the longitudinal wave and the sensitivity of the transverse waves to the different strength models.

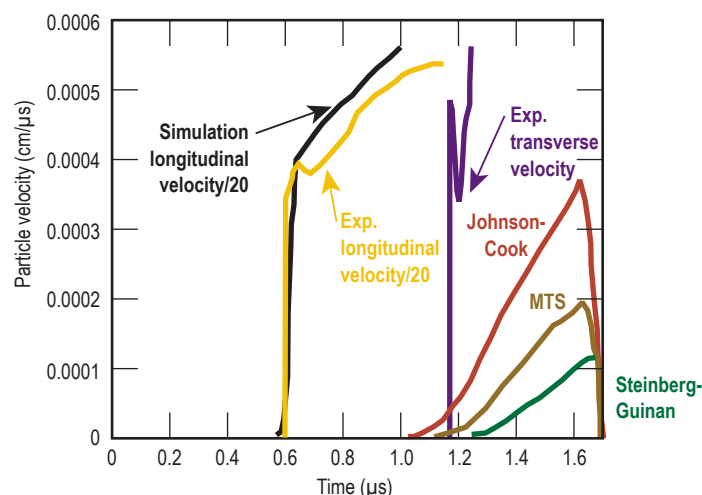


Figure 3. Experimental data showing the measured longitudinal and transverse waves. While there is good agreement between the simulation and experiment in the longitudinal wave, the experimental transverse wave is much larger, signifying a material that has higher strength than predicted.

has focused on fielding the experiment at low pressures, which includes sample preparation and characterization, simulations of the proposed experiment, and results from the initial experiments.

Sample Preparation and Characterization. The initial sample configuration is a Cu sample with a sapphire window, which was chosen due to its close impedance match. A fine diffraction grating of 1200 lines/mm, which is used to measure the normal and transverse waves, is etched into the sapphire windows, and a thin layer (~130 nm) of Cu is deposited on top of the grating. The Cu sample is then attached to the deposited Cu using epoxy on the circumference. In order to achieve a near isentropic compression, a graded density impactor is used. Diffusion bonded impactors have been characterized to understand the strength and waves imparted into the sample.

Simulations. We have performed a series of simulations (Fig. 2), which shows the validity of the proposed experiments. The simulation results show that the transverse wave, which is related to the strength of the material under pressure, is very sensitive to the strength model used. The

simulations are also used to help guide the experiments, such as determining the optimal sample and sapphire thickness.

Experimental Results. Experiments have been performed at Brown University on Cu/sapphire samples. The longitudinal and transverse wave results are shown in Fig. 3. A couple of key features are that the graded density impactor causes a ramp in the pressure (isentropic compression) which controls the strain rate to $\sim 10^5$, and that the transverse wave arrives near peak pressure. Also, the transverse signal measured is much higher than expected, signifying that the Cu is stronger than the models predict.

Related References

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FY2008 Proposed Work

In FY2008, additional low-pressure experiments and intermediate pressure experiments (150 to 300 kbar) on Cu, Ta, and V are planned at Brown University. The results from the tests will give us the necessary data to begin the development and refinement of strength models. Based on the results, the designs for a 2-in. graded density impactor and a soft recovery experiment will be explored. Simulations will continue to be conducted to aid in the design of the experiments.